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Request for grant of a patent

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29 JUL 2003

29JUL03 E826221-2 010059
P01/7700 0.00-0317722.7

1. Your reference
LRD-GB-1-449

2. Patent application number
(The Patent Office will fill in this part)
0317722.7

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*
K.U.Leuven Research and Development - Groot Begijnhof 59 - 3000 Leuven
Represented by Dr. Patrick Chaltin
Patents ADP number *(if you know it)* 779097S002
If the applicant is a corporate body, give the country/state of its incorporation: Belgium

4. Title of the invention
Foil bearings

5. Name of your agent *(if you have one)*
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*
K.U.Leuven R&D
care off:
Hubert Velge
Neaves Cottage
Neaves Lane - Glyndebourne
East Sussex BN8 5UA
Patents ADP number *(if you know it)* 804916500

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
See note (d))

Yes

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Continuation sheets of this form	
Description	9
Claim(s)	1
Abstract	
Drawing(s)	2 only

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	1
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	1 fax cover sheet 1 fee sheet with request for fax back service

11. I/We request the grant of a patent on the basis of this application.

Dr. Patrick Chaltin, T.T.O.

Signature

Date 29/07/03

12. Name and daytime telephone number of person to contact in the United Kingdom

Hubert Velge
+44 7940 540 397

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FOIL BEARINGS

FIELD OF THE INVENTION

The present invention relates to a new kind of foil bearing. The present invention relates to an air bearing comprising a flexible foil. The present invention furthermore relates to a foil bearing enabling a linear and/or rotary movement along/around an axis (i.e. a shaft). The present invention also relates to a foil air bearing with a self-aligning mechanism. The present invention furthermore relates to the use of said foil bearing in machines, more specifically in precision and/or high-speed machines and in high-speed precision spindles.

BACKGROUND OF THE INVENTION

Semiconductor fab, high-resolution scanning, and high-speed machinery are just some of the applications pushing (rolling-element) bearings to technical limits. One reason for this is friction and variations therein, which has always posed problems for precision positioning systems. More force is needed to initiate motion than to maintain it, leading to an imbalance between start and stop and leading to a stick-slip action. This problem is higher for plain bearings than for rolling bearings, because of differences in static and dynamic friction coefficients.

An option to circumvent the friction problem is air bearings, in which no lubrication is needed. Air bearings eliminate the stick-slip problem, because static friction is zero, making infinite-motion resolution theoretically possible and reducing the power loss. Most large turbines today use oil-based hydrodynamic bearings, though many new microturbines employ aerodynamic bearings to improve efficiency.
Besides smoothing stop and starts, air bearings offer less resistance (friction) to steady-state motion. Friction generates heat which, in turn, causes spindles and other components to

thermally grow, compromising precision. Air bearings generate much less heat in a given application than rolling-element or plain bearings in most cases. In fact, relative speeds must exceed about 100 ft/sec before air bearings generate any significant heat at normal air gaps. Air bearings excel in applications requiring tight velocity control such as scanning and wafer inspection, because they eliminate force ripples from recirculating ball bearings loading and unloading.

Air bearings have been operated in process fluids other than air, such as helium, xenon, air-conditioner refrigerants, liquid oxygen, and liquid nitrogen. For applications in vapor cycles, the refrigerant can be used to cool and support the foil bearings without the need for oil lubricants that can contaminate the system and reduce efficiency.

The trend to make machines faster and more precise leads to an increasing demand for air bearings. Air bearings are however very expensive and delicate. A cheap solution of an air bearing with high performance and accuracy is problematic, especially in case of bearing around a shaft. Furthermore, traditional air bearings for axial movement have a rigid form or only restricted adaptability concerning air gap geometry. The special geometry of the gap between shaft and bearing surface is difficult to create and is only ideal under certain conditions.

An attempt to overcome some of the problems has been undertaken by using air bearings made with for example orifice or with porous technology, in order to achieve a more uniform pressure distribution. Orifice compensation distributes pressurised air across a bearing face through strategically placed, precisely sized orifices and grooves. But scratches across a groove or near orifices may cause more air to escape than orifices can supply, causing a bearing to crash at normal air-supply pressures.

In general, air bearings with hard bearing surfaces are still observing problems with reliability. For example, since the running radial clearance between the shaft and a bearing is very small (usually less than 0.0005 inch for a 2-inch diameter shaft at 36,000 rpm), shaft growth caused by temperature and centrifugal force can be problematic. In addition, damping is required to suppress any whirl instability, and there can be misalignment between various rotating parts and stationary parts.

In the prior art, this problem is solved by foil bearings. While the shaft is stationary, there is a small amount of preload between the shaft and the bearing. As the shaft turns, hydrodynamic pressure is generated, pushing the foils away from the shaft and making the shaft completely airborne. This phenomenon occurs instantly during start-up at a very low speed. When the shaft is airborne, the friction loss due to shaft rotation is quite small. As the shaft grows, the foils get pushed farther away, keeping the film clearance relatively constant. In addition, the foils provide coulomb damping due to their relative sliding. This damping is essential for the stability of the machine.

Currently, foil bearings are limited to rotational axes and most of the time they are working without air supply (aerodynamic). Furthermore, in current foil bearings, the foil does not envelop the axis in a perfect way, leading to air lost and a reduction of the capacity or a malfunction of the bearing.

As a summary, there is still a need for foil air bearings with a high performance and accuracy and with different and multiple movement possibilities around an axis (rotary and linear movement). Therefore, a goal of the present is to satisfy this need by creating a new foil air bearing enabling a linear and rotary movement along/around an axis (i.e. shaft) with a high performance and with a self-aligning mechanism.

SUMMARY OF THE INVENTION

In the present invention, a new foil air bearing is being provided with a self-aligning mechanism. The present invention deals with new foil air bearings that can be used in slideways for precision machine tools, precise measuring machines, high-speed machinery and test equipment. High-speed precision spindles for turning, milling or grinding are other applications the foil bearing is designed for.

The present invention relates to a new kind of bearing. The present invention relates to a bearing comprising a flexible foil and a rigid frame. More in particular, the present invention

relates to a foil air bearing enabling a linear and/or rotary movement along/around an axis (i.e. a shaft). The present invention also relates to a new foil bearing in which the foil envelops the axis perfectly during operation.

The present invention also relates to a new foil air bearing enabling a linear and/or rotary movement along/around an axis (i.e. a shaft) and in which the foil envelops the axis perfectly during operation. The present invention furthermore relates to a new foil air bearing in which the air is supplied through the shaft. The present invention also relates to a foil bearing without an external air supply. The present invention relates to a new foil air bearing comprising a rigid frame, a flexible foil, a flexible air supply and two self-aligning cylinders, whereby the foil embraces the round rails of the cylinders.

One embodiment of the present invention relates to a new foil bearing which is externally pressurised. Another embodiment of the present invention relates to a new foil bearing for linear and/or rotary movement along/around an axis. Yet another embodiment of the present invention relates to a new foil bearing, comprising a foil extended between a first and a second attachment point on a frame and a means for supporting and positioning the foil, more in particular via two cylinders.In a preferred embodiment of the present invention, the two cylinders are self-aligning. The foil can be attached or fixed to the frame by clamping members, by welding or by gluing. It is also another embodiment of the present invention that the foil bearing comprises a flexible fluid (gas or liquid) supply. In a particular embodiment of the present invention, the flexible supply is made of plastic, rubber or any other conventient material. The foil used in the foil bearing can be selected from a metal, a plastic or any other convenient material.

One aspect of the present invention is the provision of an externally pressurised foil bearing for linear and/or rotary movement along/around an axis, compromising a foil extending between a first and a second attachment point, a flexible gas or liquid supply and two cylinders supporting and positioning the foil. More particularly, the present invention relates to an externally pressurised foil bearing for linear and/or rotary movement along/around an axis, comprising a foil extending between a first and a second clamping member, a flexible fluid supply and a means for supporting and positioning the foil.

The present invention furthermore relates to a foil bearing wherein two cylinders support and position the foil, giving the foil the necessary degrees of freedom it needs to cover the axis appropriately and enlarging the contact area.
In another embodiment of the invention, the foil of the foil bearing is additionally fixed to the middle of the frame.
It is yet another embodiment of the present invention that the foil bearing comprises multiple foils, at least two. The present invention therefore also relates to a foil bearing, comprising two different foils within one frame.
In another embodiment of the present invention, the air of the foil air bearing is supplied via the shaft.

The present invention furthermore relates to the use of said foil bearing in machines, more specifically in precision and/or high-speed machines and in high-speed precision spindels.
The invention furthermore provides a new kind of air bearing for precise and/or rapidly moving parts along or around a shaft.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 is a lateral view of the standard embodiment of the air bearing.

Fig. 2 is a longitudinal cross-sectional view of this embodiment taken along line II-II.

Fig. 3 is a longitudinal cross-sectional view of an embodiment with fluid supplied through the shaft.

Fig. 4 is a lateral view of an embodiment of the air bearing with multi-directional stiffness only using a fixation.

Fig. 5 is a longitudinal cross-sectional view of the embodiment in Fig. 4 along line V-V.

Fig. 6 is a lateral cross-sectional view of the embodiment of Fig 7 along the line VI-VI. It is an air bearing with multi-directional stiffness using additional positioning parts.

Fig. 7 is a longitudinal cross-sectional view of the embodiment of Fig 6 taken along the VII-VII.

Fig. 8 is a lateral view of an embodiment of the air bearing with multi-directional stiffness using two separate foils cutting each other.

Fig. 9 is a longitudinal cross-sectional view of the embodiment of Fig 8 along the line IX-IX.

Fig. 10 is an illustration of a possible configuration of the two cutting foils.

DETAILED DESCRIPTION OF THE INVENTION

Definitions

"Flexible supply" as used herein shall mean that the means for supply shall be bendable for more than 1°, more in particular more than 5 ° and yet more in particular more than 20° under standard conditions.

The foil bearing enables a linear or rotary movement along/around an axis (i.e. a shaft) with very low friction. It is very suited for precise positioning tools and high-speed machines.

The bearing includes a rigid frame of any convenient shape (e.g. Π), a thin flexible foil, a flexible air supply line and two small self-aligning cylinders. The foil embraces the round rail partially. Liquid or gas is supplied via the flexible hose that is attached to the foil at one or several points. Small holes in the foil (the restrictor) enable the fluid to enter the gap between shaft and foil. The thin foil is fixed to the frame by clamping plates, gluing, welding or any convenient way.

Two self-aligning cylinders guide and support the foil. They are attached to the frame by appropriate hinges. As these axes can rotate freely, for a certain amount, they make sure the foil is embracing the shaft correctly at all times, reducing alignment problems.
Stiffness in different radial directions is achieved by placing several foil bearings relatively rotated with respect to each other or by integrating two bearings in one frame.

The invention provides a new kind of air bearing for precise and/or rapidly moving parts along or around a shaft wherein the bearing has the advantage of lower cost along with minimal requirements on the shaft's surface. The bearing can also be used in precise and high-speed spindles.
The invention is based on the use of a flexible foil instead of a hard bearing surface. The air spreads through the gap between axis and foil thereby lifting the load. If the air is supplied through the foil, the hose must be very flexible not to affect the shape of the air gap.
Traditional flat gap air bearings have start-up problems, as the air pressure will only push on the surface beneath the supply hole. Temporary lift of the load is needed for operation. Our foil bearing however does not have this problem because the supply pressure will lift the foil locally. This increases the surface on which the pressure is pushing and the foil will gradually rise until a continuous air gap is built up in the whole bearing.
For good working conditions it is preferred that the foil envelops the axis perfectly during operation. If not, air will be lost and the loading capacity of the bearing will be reduced or the bearing will malfunction. To avoid aligning problems when using foil bearings a mechanism of two cylinders has been developed that enables fixation of the foil and provides sufficient degrees of freedom for the foil to surround the axis. The small cylinders support the foil while giving it the possibility to move. The point contact connection between the frame and cylinders does not impair the stiffness.

Examples

Example 1

Figs. 1 and *2* illustrate the embodiment of the present invention, which is suited for all applications. Multidirectional stiffness can be accomplished by placing several foil bearings

relatively rotated to each other. A thin flexible foil **1** embraces the shaft **2** partially. The foil is made from a suitable material, metal, plastic... The foil is fixed to a frame **3** by means of clamping plates **4**, welding or gluing. The frame can be of any arbitrary form with the same functionality (e.g. Π). To make sure the foil is surrounding the shaft appropriately a positioning system is added. Two small cylinders **5** support and guide the foil during operation. They are attached to the frame by suitable means allowing the rotation of each cylinder about the two axes normal to its geometrical axis. In this case, this is achieved by means of two small pins **6** forming point contacts in blind holes drilled in the cylinders.

A flexible hose **7** attached to the foil supplies the necessary fluid. For example pressured air is pressed between the foil and shaft thereby creating a small air gap enabling the relative displacement of bearing and shaft. Larger bearings may need several fluid inlets.

Example 2

Fig. 3 shows an implementation in which the air is supplied through the shaft. Several air inlets **8** in the shaft replace the need for a hose in the foil, thus overcoming the difficulty of air supply through the foil. This configuration can be useful for small stroke applications.

Example 3

Figs. 4 and *5* show a configuration enabling multidirectional stiffness in a single frame. This has the advantage of demanding less space than placing two separate bearings with stiffness in only one direction rotated with respect to each other. A negative aspect of this structure is the reduction in total stiffness. Fixation **9** of the foil in the middle of the frame results in two separately operating foil bearings rotated with respect to each other. Naturally, at least two supply holes are needed **10**.

Example 4

Figs. 6 and *7* illustrate an additional embodiment of the previous foil bearing. Two extra cylinders **11** ensure the proper placement of the foil and enlarge the contact area between foil and shaft. Fixation **12** of the foil in the middle is still present to avoid mutual influence. Parts can be added to shorten the length of the small pins **13**. In this figure this is done by two cylinders **14** attached to the frame by plates **15** at the end of the frame.

Example 5

Figs. 8 and *9* show a construction of a multidirectional bearing with two foils and one frame. Both foils are attached to the frame with one side on the outside and one side at the inside **16**. In order to get a large area of contact between foils and shaft the foils are cutting each other as illustrated in *Fig. 10*.

CLAIMS

1. An externally pressurised foil bearing for linear and/or rotary movement along/around a shaft, comprising a foil extending between a first and a second attachment point, a flexible fluid supply and a means for supporting and positioning the foil.
2. The externally pressurised foil bearing of claim 1, wherein a means for supporting and positioning the foil comprises two cylinders attached to the frame.
3. The externally pressurised foil bearing of claims 1 and 2, wherein the foil is additionally fixed to the middle of the frame.
4. The externally pressurised foil bearing of claim 1 to 3, wherein two foils are used in combination.
5. The externally pressurised foil bearing of claims 1 to 4 wherein said fluid is supplied via the shaft.
6. The externally pressurised foil bearing of claims 1 to 5, wherein said foil is made of metal or plastic.
7. The externally pressurised foil bearing of claims 1 to 6, wherein said flexible fluid supply is a rubber or a plastic hose.
8. The externally pressurised foil bearing of claims 1 to 7, wherein said fluid is air or a liquid.

FIG. 1

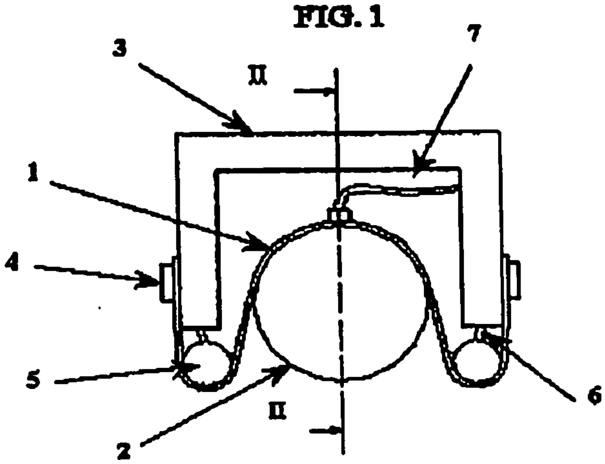

FIG. 2

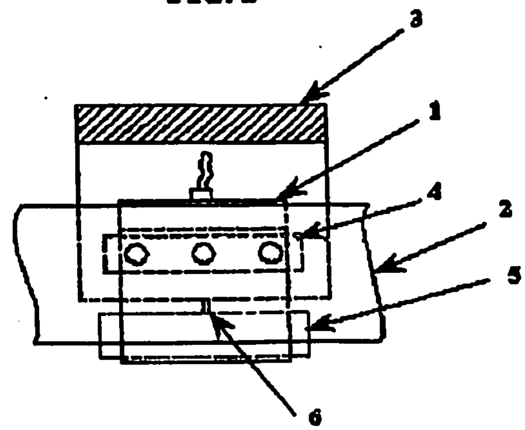

FIG. 3

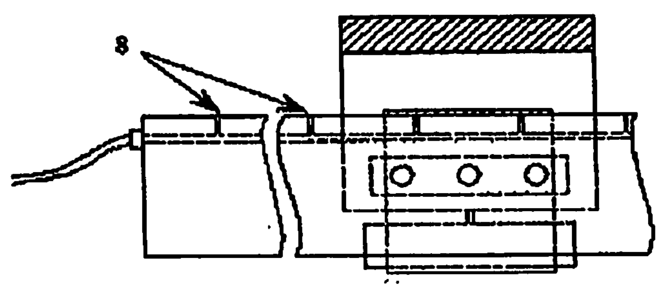

FIG. 4

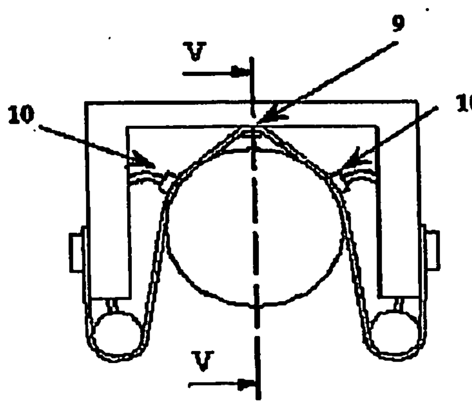

FIG. 5

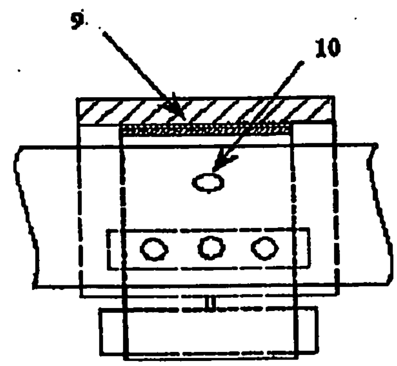

FIG. 6

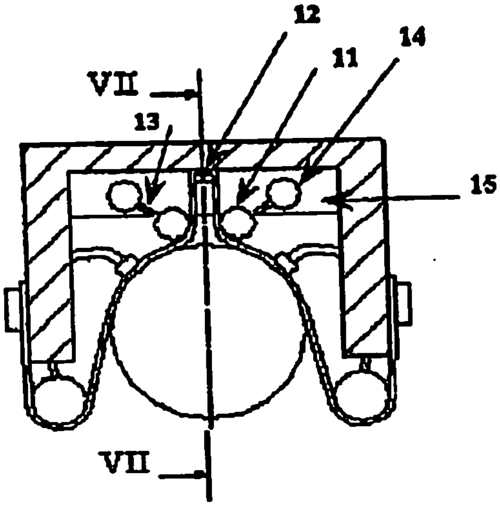

FIG. 7

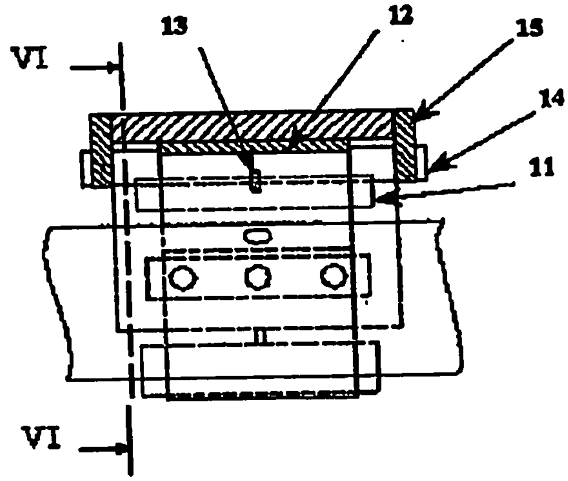

FIG. 8

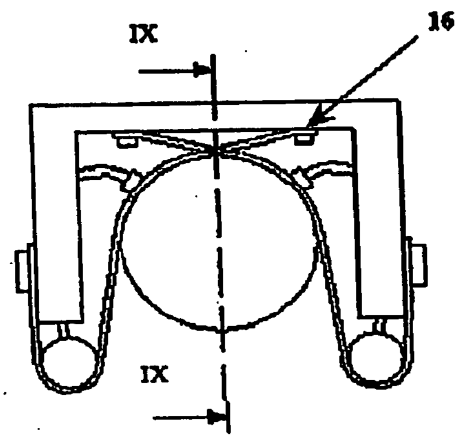

FIG. 9

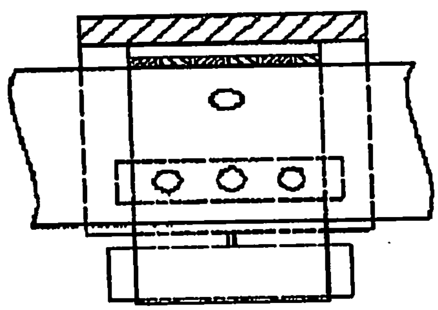

FIG. 10